

Method for hydrocarbon reservoir monitoring

The present invention relates to the geophysical mapping of subsurface physical
5 properties. More specifically the present invention relates to the injection of tracer fluids
with the aim of monitoring the subsequent distribution and migration of the tracer
within a hydrocarbon filled reservoir as a means to study the properties and fluid
content of, and fluid movement within the reservoir.

10 The ability of a geological formation to allow the passage of fluids is dependent upon
the size of the pores, their connectivity (permeability) and the properties of the fluid.
The effective permeability also depends upon the relative saturations of the various
fluids within the pores. Within hydrocarbon reservoirs, the permeability affects the flow
path of both formation fluids and injected fluids within the reservoir. It is beneficial to
15 know the reservoir permeabilities to optimize production strategies.

Various attempts have been made to trace fluid flow within the reservoir using tracers
placed into injection wells and detected during production. US patent 6,645,769
describes such a technology. The use of these methods is limited by the fact that tracers
20 can only be detected in the production well and at least two wells must be drilled.

Other methods propose the use of acoustic properties of injection fluids in order to trace
their spatial distribution through time (US patents 4,479,204; 4,969,130; 5,586,082;
6,438,069). Such methods are limited by the fact that the acoustic properties are not
25 always a reliable measure of the fluid composition.

Embodiments of the present invention seek to overcome the limitations of the above
mentioned methods by injecting tracer fluid(s) in a hydrocarbon reservoir that can be
sensed by resistivity mapping techniques as a means to study the properties and fluid
30 content of, and fluid movement within, the reservoir. The tracer fluid(s) can be any fluid
that has a conductivity different to that of the reservoir fluids.

In accordance with a first aspect of the present invention, there is provided a method for
monitoring one or more properties of a hydrocarbon reservoir with at least one borehole

characterized in that the method comprises the steps of: injecting into at least one borehole a tracer fluid which has resistivity different from the resistivity of the formation and/or formation fluid(s) and/or is able to change the resistivity of the
5 formation and/or formation fluid(s); monitoring remotely in the ocean or on land the altered resistivity of the formation and/or formation fluid(s) caused by the injected tracer fluid(s); and interpreting the data.

The method may be used to monitor and study the properties and/or geometrical extent
10 of a geological formation and/or the fluids within it. The method according to embodiments of the present invention involves the injection of fluid(s) into at least one borehole. Such injected fluid(s) will have a resistivity that contrasts with the geological formation and/or the formation fluids and/or will change the resistivity of the formation or the formation fluids. The changes that result from

injection of fluid(s) will be mapped using resistivity mapping techniques. Several existing resistivity mapping techniques are available for such a purpose. In the final step, the data are interpreted.

- 5 General resistivity mapping techniques are described for instance by US patents 4,617,518, 4,633,182; 5,770,945; 6,603,313; 6,842,006 and 6,717,411. Time-lapse remote resistivity studies have previously been used for environmental and engineering studies (Loke, M.H. 1999: Electrical imaging surveys for environmental and engineering studies). The mapping of the injected conductive/resistive solutions has
10 been used in estimation of ground water flow patterns (Aaltonen, J. 2001: Ground monitoring using resistivity measurements in glaciated terrains.; Park, S. 1998: Fluid migration in the vadose zone from 3D inversion of resistivity monitoring data.; US patent 5,825,188). A method for combined surface and wellbore resistivity mapping for reservoir monitoring purposes is described by US patent 6,739, 165. An apparatus to
15 time-lapse resistivity monitoring is described in PCT patent WO 03/023452. A more general description of remote resistivity surveys suitable for mapping of an injected conductive/resistive fluid is given by Kaufman and Hoekstra (Kaufman A.A., and Hoekstra, P., 2001: Electromagnetic soundings. Elsevier).
- 20 The techniques used to map the resistivity of the formation, formation fluids and/or injected fluid(s) may be remote, direct or a combination of the two. They may be applied in either the frequency domain or time domain. Methods may include, but are not restricted to, performing resistivity mapping using controlled source electromagnetic, magnetotelluric, galvanic methods or any combination of these. The
25 data can be collected by airborne survey, from land-based measurements and/or marine-based measurements. Data collection can also be undertaken within the subsurface using detectors placed within one or more boreholes. The source of the electromagnetic, electric or magnetic field may be airborne, land or marine-based or placed within the borehole. The borehole and/or well casing may also be used as a source, or part of a
30 source. Any combination of source and receiver location is potentially possible.

The tracer is an injection fluid with an electrical resistivity that contrasts with the formation and/or formation fluids. The injection fluid(s) may also have the capacity to change the resistivity of the formation or formation fluids by biological, chemical or
35 physical means. The resistivity of the injected fluid(s) may be changed through time to enable the tracing of fluid movement with the formation.

The injected fluid distribution at a certain time or at time intervals is detected and mapped using remote and/or direct resistivity mapping techniques well known in geophysics. The electrical resistivity is a parameter which is highly dependent on the fluid type. Resistivity mapping has been used for hydrocarbon prospecting as described
5 in US patents 4,617,518; 4,633,182; 6,603,313; 5,770,945 ; 6,842,006 and 6,717,411.
Its use for reservoir monitoring purposes is described in US patent 6,739,165.

The method can be used once at least one borehole has been drilled into the formation. The method may include making resistivity observations on the formation prior to
10 injection, although this is not essential. In addition the injected fluid(s) or mixture of injected and formation fluids can be ignited. By mapping resistivity once or at selected time intervals during and/or after injection, the flow path of the injected fluid(s) and consequently the permeability structure and fluid content of the formation can be determined. The resistivity or other properties of the injected tracer fluid(s) may be
15 varied with time.

The procedure of monitoring and performing resistivity mapping can involve processing, migration, modeling and/or inversion of the data. Time lapse data can be processed by joint-inversion and/or joint-processing of the resistivity data collected at
20 different time intervals.

Seismic, gravity, magnetic and other geophysical data, in addition to geological data, production data, reservoir modeling and reservoir simulation may also be used in any combination with resistivity measurements to map the distribution of the injected
25 fluid(s) or its alteration effects. This includes using data before, during and/or after resistivity mapping.

It is well known that seismic surveys are poor at detecting fluid properties and distribution, whilst these properties are better detected by resistivity surveys. The
30 tracing approach according to embodiments of the present invention thus provides significant advantages over existing methods.

Applications of the invention include:

- 1) The monitoring of fluid distribution within a hydrocarbon reservoir, prior to and
35 during production.
- 2) The estimation of the fluid content (including saturation) porosity and permeability structure of a hydrocarbon filled reservoir or reservoir analogue.

Example

- 5 An example of a typical application of the invention would be in hydrocarbon production for enhanced recovery purposes. In this case the injection fluid could be, but is not limited to, solutions of hydrochloric acid (HCl) and/or sodium-chloride (NaCl) in water which are highly conductive. The injection of such tracer fluid(s) into a reservoir will cause a high resistivity contrast with respect to surrounding formations and the
- 10 hydrocarbons within the reservoir. Such resistivity contrasts can be identified by using suitable, including existing, resistivity mapping methods. For example it is possible to use controlled source electromagnetic sounding where a horizontal dipole antenna and a set of electromagnetic field receivers are placed on the seafloor or according to any other relevant acquisition configuration configuration. Similarly, the resistivity contrast
- 15 can be identified by placing one or more dipole antennae and/or one or more receivers within wells. There is a number of different configurations that have the potential to identify the resistivity contrasts and the idea is flexible to different set-ups. By studying the propagation of the tracer fluid(s), it is possible to estimate the parameters of the reservoir, including movements of hydrocarbons, fluid content, permeability, porosity
- 20 and more. There may be additional benefits of injecting tracer fluid(s) such as increased recovery by improved secondary permeability and porosity.

C l a i m s

- 1.
- 5 Method for monitoring one or more properties of a hydrocarbon reservoir with at least one borehole
c h a r a c t e r i z e d i n that the method comprises the steps of:
injecting into at least one borehole a tracer fluid which has resistivity different from the
resistivity of the formation and/or formation fluid(s) and/or is able to change the
10 resistivity of the formation and/or formation fluid(s);
monitoring remotely in the ocean or on land the altered resistivity of the formation
and/or formation fluid(s) caused by the injected tracer fluid(s); and interpreting the data.
- 2.
- 15 The method according to claims 1, wherein the resistivity monitoring also is performed in wells.
- 3.
- The method according to claims 1 to 2, wherein the monitoring is performed at repeated
20 time intervals.
- 4.
- The method according to any of claims 1 to 3, wherein the method further comprises
determining the geometrical extent of the injected and/or formational fluid.
25
- 5.
- The method according to any of claims 1 to 4, wherein the injected fluid has chemical
and/or physical and/or biological properties, which enables it to change the resistivity of
the formation and/or formation fluid(s).
30
- 6.
- The method according to any of claims 1 to 5, wherein injection and/or formation fluid
or any mixture of the two fluids is ignited.

7.

The method according to any of claims 1 to 6, wherein the monitoring is performed by using controlled source electromagnetic methods including airborne, land, and marine cases, including receivers and/or source placed inside or outside one or more boreholes.

8.

The method according to any of claims 1 to 7, wherein the monitoring is performed by using magnetotelluric methods inside or outside a borehole, on land, in the air or at sea.

9.

The method according to any of claims 1 to 8, wherein the monitoring is performed using galvanic methods inside or outside a borehole, on land, in the air or at sea.

10.

The method according to any of claims 1 to 9, wherein the interpretation is performed by using frequency domain method.

11.

The method according to any of claims 1 to 9, wherein the interpretation is performed by using time domain method.

12.

The method according to any of claims 1 to 11, wherein the monitoring of injected fluid comprises joint processing and/or inversion of resistivity mapping data sets collected at different time intervals.

13.

The method according to claim 1 or claim 12, wherein seismic survey data and/or gravity survey data and/or magnetic survey data are used in addition to resistivity data during the process of monitoring the injected fluid.

14.

The method according to any of claims 1 to 13, wherein the borehole and/or its casing are used as a source and/or receiver or a part of a source and/or receiver for resistivity measurements.

15.

The method according to any of claims 1 to 14, wherein the resistivity and/or other properties of injection fluid are varied with time.

16.

The method according to any of claims 1 to 15, wherein geophysical data and/or geological data and/or production data and/or reservoir modeling and/or reservoir simulation is used in the interpretation